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TECHNICAL NOTE

Coronal plane knee laxity measurement: Is computer-assisted navigation useful?

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KEYWORDS

Knee;
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Summary

Introduction: The goal of this observational study is to measure the physiological laxity of a knee, supposedly normal in the coronal plane, at 0 and 90° of flexion with a navigation system that can be used during total knee replacement.

Hypothesis: The physiological laxity measured by this navigation system is different from the results already published using other measurement devices.

Materials and methods: Twenty patients consecutively operated on for an isolated anterior cruciate ligament injury were selected. Medial and lateral laxities at 0 and 90° of knee flexion were measured by the navigation system during cruciate replacement.

Results: The mean medial laxity in extension was $3.6 \pm 1.2^\circ$. The mean lateral laxity in extension was $4.1 \pm 1.9^\circ$. The mean medial laxity at 90° of flexion was $2.1 \pm 1.2^\circ$. The mean lateral laxity at 90° of flexion was $3.7 \pm 1.2^\circ$. The medial and lateral laxities in extension were not asymmetric. The medial and lateral laxities at 90° of flexion were asymmetric. Medial laxities in extension and at 90° of flexion were asymmetric. Lateral laxities in extension and at 90° of flexion were not asymmetric.

Discussion: The data collected in our study suggest, during total knee replacement, the following tolerable ligamentous balance: medial and lateral laxities in extension about 3°, medial laxity at 90° of flexion about 2°, and lateral laxity at 90° of flexion about 4°.

Level of evidence: Level IV. Prospective study.

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Introduction

Restoration of appropriate coronal laxity is recommended during total knee arthroplasty (TKA). Ligamentous balance has been studied in a number of theoretical and practical papers following Insall's report [1]. These studies are clearly

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founded on knowledge of physiological coronal knee laxity of the normal knee. This laxity was initially defined based on cadaveric studies with experimental measurement techniques whose use is problematic during conventional surgery [2,3].

More recently, *in vivo* studies have been published. Ståhelin et al. [4] described a measurement technique with radiographic stress images and a calibrated force but did not report numerical data. Heesterbeeck et al. [5] used this technique on 30 patients with no knee injury. Okazaki et al. [6] conducted a similar study. Tokuhara et al. [7] used MRI. All of these studies used measurement techniques that are impossible to reproduce during knee prosthesis implantation, which therefore cannot be used to check intraoperative quality. The simple and automatic transfer of the results of these studies to intraoperative management is uncertain because each measurement technique has its own confounding factors.

Computer-assisted navigation is used by many teams for TKA. Historically, these tools were developed to optimize bone resections [8,9]. Later, they were adapted to intraoperative management of ligamentous balance [10,11]. It therefore seemed valuable to define physiological knee laxity measured with this type of system so as to eliminate the potential errors related to the difference between the measurement systems used.

We therefore conducted an observational study whose goal was to define the laxity of the presumably normal knee in the coronal plane in extension and at 90° flexion using a computer-assisted navigation system that can be used during implantation of a total knee prosthesis. Our hypothesis was that the physiological laxity measured with this system is different from the measurements published previously with other measurement systems.

Materials and methods

The study population comprised 20 patients operated consecutively for an isolated tear of the anterior cruciate ligament (ACL), with no meniscus lesion, and in whom the clinical examination showed no pathological laxity in the coronal plane: 14 men and six women, with a mean age of 24 years (range, 18–36 years). All patients provided written consent for this study.

We systematically used the image-free computer-assisted OrthoPilot® navigation system (B-Braun Aesculap, Tuttlingen, Germany) for ACL reconstruction [12]. The technique requires implantation of two bicortical screws, one in the distal part of the femur and the other in the proximal part of the tibia. For the needs of this study, before ACL reconstruction, we used the application dedicated to tibial valgus osteotomy [13]. This application uses the same bicortical screws and the only additional steps related to the study were specific kinematic and anatomic registrations of this application, lasting between five and eight minutes. After registration of the anatomic and kinematic data on the operated lower limb, the system displays online the flexion–extension angle of the knee and the mechanical femorotibial angle in the coronal plane (Fig. 1), with a normal value of 0° in absence of coronal deviation. The femorotibial angle at 0° of extension in the rest position

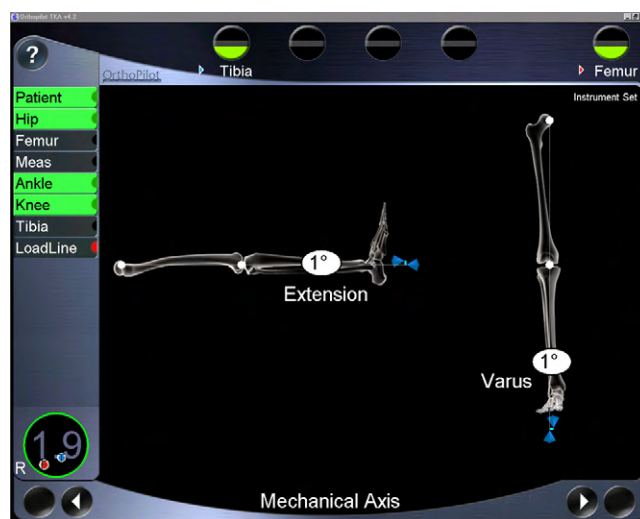


Figure 1 Information displayed online by the navigation system.

was recorded, then with maximal force in varus and valgus applied manually. The same angles were then measured at 90° flexion. The positive values were attributed to varus angles. ACL reconstruction was then performed by means of the usual navigated technique.

The analysis was performed after registration of all the data. For each patient, we calculated:

- medial laxity in extension: the difference between the anterior-posterior view (AP) AP tibiofemoral angle in extension in the rest position and the AP tibiofemoral angle in extension with maximum valgus;
- lateral laxity in extension: the difference between the AP tibiofemoral angle in extension in the rest position and the AP tibiofemoral angle in extension with maximum varus;
- medial laxity in flexion: the difference between the AP tibiofemoral angle at 90° flexion in the rest position and the AP tibiofemoral angle at 90° flexion with maximum valgus;
- lateral laxity in flexion: the difference between the AP tibiofemoral angle at 90° flexion in the rest position and the AP tibiofemoral angle at 90° flexion with maximum varus.

The following statistical analyses were performed using the Wilcoxon test for paired measurements with a 5% limit of significance; the distributions were assumed to be non-normal:

- the difference in the same patient between the AP tibiofemoral angle in extension in the rest position and the AP tibiofemoral angle in extension with maximum valgus, testing for the presence of medial laxity in extension;
- the difference in the same patient between the AP tibiofemoral angle in extension in the rest position and the AP tibiofemoral angle in extension with maximum varus, testing for the presence of lateral laxity in extension;
- the difference in the same patient between the AP tibiofemoral angle at 90° flexion in the rest position and the AP tibiofemoral angle at 90° flexion with maximum valgus, testing for the presence of medial laxity in flexion;

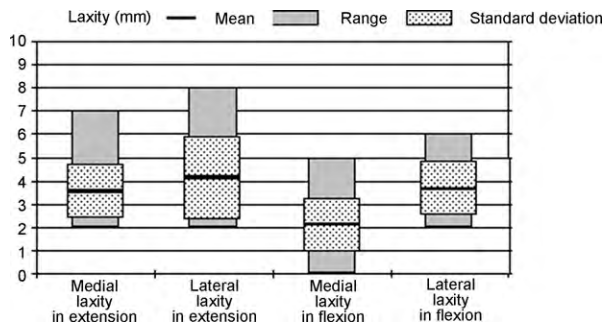


Figure 2 Results (mm): mean, standard deviation, range.

- the difference in the same patient between the AP tibiofemoral angle at 90° flexion in the rest position and the AP tibiofemoral angle at 90° flexion, testing for the presence of lateral laxity in flexion;
- the difference in the same patient between medial and lateral laxity in extension, testing the symmetry of the laxities in extension;
- the difference in the same patient between medial and lateral laxity in flexion, testing the symmetry of the laxities in flexion;
- the difference in the same patient between medial laxity in extension and flexion, testing the symmetry of the medial laxities;
- the difference in the same patient between lateral laxity in extension and flexion, testing the symmetry of the lateral laxities.

Results

Extension

The AP tibiofemoral angle in the rest position was $0.4 \pm 3.2^\circ$ (range, -6 to 5°). The AP tibiofemoral angle with maximum valgus was $-3.2 \pm 3.4^\circ$ (range, -9 to 2°). The AP tibiofemoral angle with maximum varus was $4.5 \pm 3.1^\circ$ (range, -2 to 9°). The medial laxity in extension was $3.6 \pm 1.2^\circ$ (range, $2-7^\circ$). The lateral laxity in extension was $4.1 \pm 1.8^\circ$ (range, $2-8^\circ$) (Table 1, Fig. 2).

The difference between the AP tibiofemoral angle in the rest position and the AP tibiofemoral angle with maximum valgus in the same patient was significant ($p < 0.001$): the medial laxity in extension was significantly non-zero. The difference between the AP tibiofemoral angle in the rest position and the AP tibiofemoral angle with maximum varus in the same patient was significant ($p = 0.001$): the lateral laxity in extension was significantly non-zero.

The difference of lateral laxity minus medial laxity in the same patient was $0.6 \pm 2.0^\circ$ (range, -2 to 5°); this difference was not significant ($p = 0.14$): the laxities in extension were not asymmetric.

Flexion

The AP tibiofemoral angle in the rest position was $1.9 \pm 2.6^\circ$ (range, -3 to 7°). The AP tibiofemoral angle with maximum valgus was $-0.2 \pm 3.1^\circ$ (range, -8 to 5°). The AP tibiofemoral angle with maximum varus was $5.5 \pm 2.9^\circ$

(range, $0-11^\circ$). The medial laxity in flexion was $2.1 \pm 1.2^\circ$ (range, $0-5^\circ$). The lateral laxity in flexion was $3.7 \pm 1.2^\circ$ (range, $2-6^\circ$).

The difference between the AP tibiofemoral angle in the rest position and the AP tibiofemoral angle with maximum valgus in the same patient was significant ($p = 0.001$): the medial laxity in flexion was significantly non-zero. The difference between the AP tibiofemoral angle in the rest position and the AP tibiofemoral angle with maximum varus in the same patient was significant ($p < 0.001$): the lateral laxity in flexion was significantly non-zero.

The difference of lateral laxity minus medial laxity in the same patient was $1.6 \pm 1.2^\circ$ (range, -2 to 3°); this difference was significant ($p = 0.001$): the laxities in flexion were asymmetric.

Extension/flexion

The difference of medial laxity in flexion minus lateral laxity in extension in the same patient was $-1.5 \pm 1.8^\circ$ (range, -6 to 2°); this difference was significant ($p = 0.003$): the medial laxities in extension and flexion were asymmetric. The difference in lateral laxity in flexion minus lateral laxity in extension in the same patient was $-0.5 \pm 1.7^\circ$ (range, -4 to 3°); this difference was not significant ($p = 0.38$): the lateral laxities in extension and flexion were not asymmetric.

Discussion

Knowledge of the normal laxity of a knee in the coronal plane is necessary in the currently endless discussion on the desired laxity for a TKA. The studies conducted by Markolf et al. [2] have served as a model for many other authors, who are more focused on the central pivot. For example, Van Damme et al. [3] found normal coronal laxity values on the order of 2° in extension and 6° in flexion, differing little between the medial and lateral sides. These cadaveric studies have the disadvantage of being far removed from clinical reality, with a potentially unknown bias.

The clinical studies have been essentially conducted on stress radiographs. Okazaki et al. [6] found mean medial laxities of 2.4° in extension and 1.7° in flexion, and mean lateral laxities of 4.9° in extension and 4.8° in flexion. Heesterbeek et al. [5] found mean medial laxities of 2.3° in extension and 2.5° in flexion, and mean lateral laxities of 2.8° in extension and 3.1° in flexion. Other, more sophisticated techniques have also been used, with substantially different results. Using a mechanical goniometer, Yoo et al. [14] found mean laxities in extension of 4° on the medial side and 7° on the lateral side. In a study using stress measurement on MRI, Tokuhara et al. [7] found laxities at 90° flexion of 3° on the medial side and 8° on the lateral side. Although they measured laxity in the living subject, all these clinical studies had the main disadvantage of using measurement techniques that cannot be used during TKA: therefore, systematic error related to the use of two different measurement techniques is possible. Tokuhara et al. [15] found a 1.5° error between the MRI and X-ray measurements of laxity in flexion, an important bias in terms of the absolute value of the laxity measured on the order of 5° . Using the same technique to define physiological laxity and then measuring laxity during

Table 1 Results.

Case no.	A	B	C	D	E	F	G	H	I	J
1	-2	-4	1	2	1	6	2	3	1	4
2	2	-2	6	1	-3	6	4	4	4	5
3	-2	-9	2	0	-1	2	7	4	1	2
4	-3	-7	0	-1	-1	1	4	3	0	2
5	0	-2	3	4	2	6	2	3	2	2
6	2	-2	4	2	0	6	4	2	2	4
7	5	0	9	2	1	5	5	4	1	3
8	4	1	6	6	4	11	3	2	2	5
9	3	0	7	2	0	6	3	4	2	4
10	-3	-5	1	0	-1	3	2	4	1	3
11	1	-3	7	5	3	8	4	6	2	3
12	-2	-5	6	1	-2	7	3	8	3	6
13	4	1	7	4	2	8	3	3	2	4
14	-1	-6	7	3	1	7	5	8	2	4
15	2	-2	5	2	1	5	4	3	1	3
16	4	1	6	3	1	5	3	2	2	2
17	-2	-6	2	-1	-5	4	4	4	4	5
18	-3	-6	4	-2	-4	3	3	7	2	5
19	5	2	9	7	5	11	3	4	2	4
20	-6	-9	-2	-3	-8	0	3	4	5	3

A: AP coronal tibiofemoral angle at 0° extension in rest position; B: AP coronal tibiofemoral angle at 0° extension with maximum varus force; C: AP coronal tibiofemoral angle at 0° extension with maximum valgus force; D: AP coronal tibiofemoral angle at 90° flexion in rest position; E: AP coronal tibiofemoral angle at 90° flexion with maximum varus force; F: AP coronal tibiofemoral angle at 90° flexion with maximum valgus force; G: medial laxity at 0° extension; H: lateral laxity at 0° extension; I: medial laxity at 90° flexion; J: lateral laxity at 90° flexion.

TKA eliminate this source of error. To our knowledge, this study is the first to eliminate this bias in a clinical study.

The choice of the study population (patients who had isolated laxity of the ACL) is clearly debatable, because the absence of medial laxity was defined only by the clinical examination whose precision should be considered with caution, notably for low-level laxities. However, it has been experimentally demonstrated that resection of the ACL does not produce abnormal medial valgus laxity [16,17]. It can therefore be accepted that in the absence of significant clinical abnormality, medial laxity in the subjects studied could be considered normal.

Computer-assisted navigation has been developed as an aid to TKA implantation, initially to optimize bone resections [8,9]. Using this tool to measure laxity is more recent, but has been validated experimentally [3] as well as clinically [10,11]. These sophisticated tools may provide better performance than the spacers used in conventional techniques. The values found in the present study are both near and distant from the values defined by previous authors with the other measurement tools reported above: 4° of medial and lateral laxity in extension, 2° of medial laxity, and 4° of lateral laxity in flexion.

One aspect that can be criticized in this study is the fact that the creation of maximal laxity was not calibrated but rather applied manually. Ligaments are viscoelastic structures whose deformation depends on the force applied [18]. Calibrating this would have required, however, a more aggressive technique, such as temporary fixation of intraosseous screws or use of a joint distractor. We found this to be ethically unwarranted.

The recording of maximal displacement, located on the plateau of the tension/length curve, allows us to assume that the bias related to our measurement technique is minimized, because a variation in the force applied is probably only expressed, on the plateau of the curve, by a minimal and insignificant modification in laxity. Two previous studies showed that intraobserver and interobserver reliability of axis and laxity measurements with the navigation systems used was acceptable [19,20], with a maximum variability of 2° in conditions similar to those reproduced in this study. This value is not insignificant given the laxities measured in this study, and the results could therefore be challenged. However, it is striking to note that conventional intraoperative measurements, usually taken without a calibration or measurement device, are almost never criticized on this point. Therefore, it can at least be concluded that the use of a navigation system for measuring laxity improves the objectiveness of the measurements compared to conventional techniques.

The absence of calibration when laxity is created also makes it impossible to guarantee equality between flexion and extension. We attempted to manage this bias by blocking the hip in a position of maximum internal or external rotation before measuring laxity in flexion, so as to record maximum displacement in both flexion and extension. We are aware that this technique should be applied cautiously if the patient has a total hip prosthesis, but this configuration is only found in a small proportion of TKA patients.

Another weakness of this study is the absence of comparative measurement of laxity using another measurement technique for comparison. The reference technique was rep-

resented by the varus and valgus stress images. These images are not included in our usual procedure during ACL reconstruction and we did not deem it useful to expose patients to additional irradiation that was not justified by a therapeutic objective.

The statistical analysis showed that the difference between the mean laxity in extension on the medial side and the lateral side was not significant. This result supports the two studies cited above [3,5], but contradicts two others [6,14]. This may stem from the small sample analyzed in our study. It is also a probable consequence of the subjects' physiological variability.

On the other hand, the statistical analysis showed that the difference between mean laxity in flexion on the medial side and the lateral side was significant, with lateral laxity higher in general. These results support those found by Okazaki et al. [6] and Tokuhara et al. [7], but contradict the studies by Van Damme et al. [3] and Stähelin et al. [4]. Here again, the size of the population studied and physiological variability can be put forward. The asymmetry of medial and lateral laxities in flexion can explain the fact that lateral lift-off in flexion is possible in normal subjects [21].

It therefore seems that the notion of ligamentous balance is a very relative notion if one adheres to the physiological laxity of the normal knee. Balance does not mean perfect numerical equality of all laxities, but restoration of physiological laxities. This raises the physiological variability demonstrated by this study: reconstructing all knees based on a single model with mean laxities for every case implies that certain knees will be reconstructed with a laxity that is significantly different from their physiological laxity. However, today it is impossible to know the initial physiological laxity a posteriori in an arthritic patient and during TKA. The influence of osteoarthritis on coronal laxity is currently being debated: increased by progressive distension according to Wada et al. [22], reduced by progressive retraction according to Brage et al. [23]. Sharma et al. [24] have even hypothesized that excessive physiological coronal laxity may predispose the patient to osteoarthritis.

In view of their experience, several authors have proposed a range of desired laxity after TKA: 4° of coronal laxity in extension on both sides for Ishii et al. [25], between 4 and 8° coronal laxity at 20° flexion on both sides for Kuster et al. [26], and 7° of lateral laxity in flexion for Romero et al. [27]. The recommendations generally lack precision, reflecting physiological variability. Our study, therefore, cannot define the desired laxity during TKA. Individualization is undoubtedly good, but beyond our current technical means. It does seem logical, however, to come close to mean values, as recommended for TKA with mean physiological axes.

We believe the present study to be an argument for balancing laxities in extension during TKA. To approach our results, we suggest leaving medial and lateral laxity in extension on the order of 3°, eventually accepting a 2° difference in either direction. This is also for us an argument for not seeking to perfectly balance laxities in flexion during TKA. To approach our results, we suggest leaving medial and lateral laxity in flexion on the order of 2° and lateral laxity in flexion on the order of 4°, with 2° of difference acceptable in either direction.

Even in experienced hands, obtaining good ligament balance is difficult during TKA [28]. In this sense, navigation could become an appreciable aide [5,10,11], particularly for precise adjustment such as we suggest. However, one must not overestimate the isolated influence of residual laxity after TKA, because other factors may be more important for the kinematics of knee prostheses [29].

Conclusion

Optimization of the laxities during TKA is a complex question, and it was not our ambition to provide a simple response. This study merely aims to define the physiological coronal laxities of a knee considered normal with a measurement instrument that can be used during surgery and therefore, with no bias related to the use of different instruments. Knowledge of these normal laxities should be the basis for surgical reasoning to choose the desired laxity during the intervention. Navigation could provide more precise adjustment of laxity than traditional mechanical instruments.

Conflict of interest statement

None.

References

- [1] Insall JN. Technique of total knee replacement. Instr Course Lect 1981;30:324.
- [2] Markolf KL, Mensch JS, Amstutz HC. Stiffness and laxity of the knee – the contributions of the supporting structures. A quantitative in vitro study. J Bone Joint Surg Am 1976;58:583–94.
- [3] Van Damme G, Defoort K, Ducoulombier Y, Van Glabbeek F, Bellemans J, Victor J. What should the surgeon aim for when performing computer-assisted total knee arthroplasty? J Bone Joint Surg Am 2005;87(Suppl. 2):52–8.
- [4] Stähelin T, Kessler O, Pfirrmann C, Jacob HA, Romero J. Fluoroscopically assisted stress radiography for varus–valgus stability assessment in flexion after total knee arthroplasty. J Arthroplasty 2003;18:513–5.
- [5] Heesterbeek PJC, Verdonschot N, Wymenga AB. In vivo knee laxity in flexion and extension: a radiographic study in 30 older healthy subjects. Knee 2008;15:45–9.
- [6] Okazaki K, Miura H, Matsuda S, Takeuchi N, Mawatari T, Hashizume M, et al. Asymmetry of mediolateral laxity of the normal knee. J Orthop Sci 2006;11:264–6.
- [7] Tokuhara Y, Kadoya Y, Nakagawa S, Kobayashi A, Takaoka K. The flexion gap in normal knees. An MRI study. J Bone Joint Surg Br 2004;86:1133–6.
- [8] Saragaglia D, Picard F, Chaussard C, Montbarbon E, Leitner F, Cinquin P. Mise en place des prothèses totales du genou assistée par ordinateur: comparaison avec la technique conventionnelle. Rev Chir Orthop Reparatrice Appar Mot 2001;87:18–28.
- [9] Jenny JY, Boeri C. Implantation d'une prothèse totale de genou assistée par ordinateur. Rev Chir Orthop Reparatrice Appar Mot 2001;87:645–52.
- [10] Saragaglia D, Chaussard C, Rubens-Duval B. Navigation as a predictor of soft tissue release during 90 cases of computer-assisted total knee arthroplasty. Orthopedics 2006;29(10 Suppl.):S137–8.
- [11] Picard F, Deakin AH, Clarke IV, Dillon JM, Kinninmonth AW. A quantitative method of effective soft tissue management for

- varus knees in total knee replacement surgery using navigational techniques. *Proc Inst Mech Eng H* 2007;221:763–72.
- [12] Hart R, Krejzla J, Sváb P, Kocis J, Stipčák V. Outcomes after conventional versus computer-navigated anterior cruciate ligament reconstruction. *Arthroscopy* 2008;24:569–78.
- [13] Saragaglia D, Roberts J. Navigated osteotomies around the knee in 170 patients with osteoarthritis secondary to genu varum. *Orthopedics* 2005;28(10 Suppl.):s1269–74.
- [14] Yoo JC, Ahn JH, Sung KS, Wang JH, Lee SH, Bae SW, et al. Measurement and comparison of the difference in normal medial and lateral knee joint opening. *Knee Surg Sports Traumatol Arthrosc* 2006;14:1238–44.
- [15] Tokuhara Y, Kadoya Y, Kanekasu M, Kondo M, Kobayashi A, Takaoka K. Evaluation of the flexion gap by axial radiography of the distal femur. *J Bone Joint Surg Br* 2006;88:1327–30.
- [16] Ellis BJ, Lujan TJ, Dalton MS, Weiss JA. Medial collateral ligament insertion site and contact forces in the ACL-deficient knee. *J Orthop Res* 2006;24:800–10.
- [17] Lujan TJ, Dalton MS, Thompson BM, Ellis BJ, Weiss JA. Effect of ACL deficiency on MCL strains and joint kinematics. *J Biomech Eng* 2007;129:386–92.
- [18] Zalzal P, Papini M, Petrucelli D, De Beer J, Winemaker MJ. An in vivo biomechanical analysis of the soft-tissue envelope of osteoarthritic knees. *J Arthroplasty* 2004;19:217–23.
- [19] Jenny JY, Boeri C. Reproducibility of the intra-operative measurement of the mechanical axes of the lower limb and of the femoral trans-epicondylar axis during total knee replacement by a non-image based navigation system. In: Troccaz J, Merloz P, editors. *Surgetica 2002. Gestes médico-chirurgicaux assistés par ordinateur : outils et applications*. Sauramps médical; 2002. p. 241–4.
- [20] Jenny JY, Boeri C, Picard F, Leitner F. Reproducibility of intra-operative measurement of the mechanical axes of the lower limb during total knee replacement with a non-image-based navigation system. *Comput Aided Surg* 2004;9:161–5.
- [21] Bourne RB, Finlay JB, Papadopoulos P, Rorabeck CH, Andreae P. In vitro strain distribution in the proximal tibia. Effect of varus-valgus loading in the normal and osteoarthritic knee. *Clin Orthop Relat Res* 1984;188:285–92.
- [22] Wada S, Imura S, Baba H, Shimada S. Knee laxity in patients with osteoarthritis and rheumatoid arthritis. *Br J Rheumatol* 1996;35:560–3.
- [23] Brage ME, Draganich LF, Pottenger LA, Curran JJ. Knee laxity in symptomatic osteoarthritis. *Clin Orthop Relat Res* 1994;304:184–9.
- [24] Sharma L, Lou C, Felson DT, Dunlop DD, Kirwan-Mellis G, Hayes KW, et al. Laxity in healthy and osteoarthritic knees. *Arthritis Rheum* 1999;42:861–70.
- [25] Ishii Y, Matsuda Y, Ishii R, Sakata S, Omori G. Coronal laxity in extension in vivo after total knee arthroplasty. *J Orthop Sci* 2003;8:538–42.
- [26] Kuster MS, Bitschnau B, Votruba T. Influence of collateral ligament laxity on patient satisfaction after total knee arthroplasty: a comparative bilateral study. *Arch Orthop Trauma Surg* 2004;124:415–7.
- [27] Romero J, Stähelin T, Binkert C, Pfirrmann C, Hodler J, Kessler O. The clinical consequences of flexion gap asymmetry in total knee arthroplasty. *J Arthroplasty* 2007;22:235–40.
- [28] Griffin FM, Insall JN, Scuderi GR. Accuracy of soft tissue balancing in total knee arthroplasty. *J Arthroplasty* 2000;15:970–3.
- [29] Ishii Y, Noguchi H, Matsuda Y, Takeda M, Walker SA, Komistek RD. Effect of knee laxity on in vivo kinematics of meniscal-bearing knee prostheses. *Knee* 2007;14:269–74.